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Energy and Carbon Scenarios for China:

Review of Previous Studies and Issues for Future Work

Produced for the

Chinese Energy and Carbon Scenarios Project

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Background

The Chinese Energy and Carbon Scenarios Project

The Chinese Energy and Carbon Scenarios Project (Scenarios Project) was begun in 1999 with the aim of assisting the Basic Infrastructure Department of the State Development Planning Commission (SDPC) to formulate the Chinese government's Tenth Five-Year Plan (2001-2005) and the Medium to Long Term Strategy (2006 beyond) for Energy Efficiency. These plans will include policies and action plans that promote sustainable and low carbon development. The project will provide policy-makers with suggestions on methods and relevant analytical tools for plan formulation and with policy recommendations derived from detailed study and analysis of scenarios for future development. The project is led by the Beijing Energy Efficiency Center (BECon) of China's Energy Research Institute, assisted by other research organizations in China, and assisted by an international team led by the Lawrence Berkeley National Laboratory. This project is supported by the China Sustainable Energy Program (established by the David and Lucille Packard Foundation and administered by the Energy Foundation) and by the Sustainable Energy Programme of the Shell Foundation.

Purpose of This Paper

This paper is intended as background for the stakeholders to the Chinese Energy and Carbon Scenarios Project. In particular, it will provide a common reference point for those involved in workshops related to this project, and those who otherwise help to shape the objectives and parameters of the scenarios to be constructed, and the methods used to quantify them.

The paper provides a review of major energy and carbon emissions scenarios for China over the past several years, each of which has made a unique and valuable contribution to understanding of China's future economic development, energy use patterns, and greenhouse gas emissions. The studies are categorized by the organizations that sponsored and conducted them, objectives, approaches and methods, and data. We compare the assumptions used in the various studies and their results, pointing out features that may be relevant to the current project, as well as deficiencies.

This paper also distinguishes the Chinese Energy and Carbon Scenarios project from previous scenario exercises. One key difference is that this project is intended to develop a scenario-based modeling tool and associated databases that will be useful in ongoing formulation of national policies and plans for energy efficiency. The model developed in this project will provide a high level of technical detail, enabling policy analysis of choices that China actually faces, now and in the future. In addition, this paper identifies some key issues that the Chinese Energy and Carbon Scenarios Project will address.

Introduction to Previous Scenarios Studies

For decades, Chinese researchers and planners have been preparing medium- and long-term projections of energy production and use, and, more recently, projections of energy-related pollutant emissions as well. Thinking about energy futures in China, as elsewhere, has often followed a line of reasoning that links energy use to economic output in a relatively simple fashion, e.g., using a single indicator—energy intensity (energy use per unit of economic output)—to represent the complex interactions of a country's energy system and economy.

Typically, projections of energy made for industrializing countries assume that energy intensity will tend to increase. This has indeed been the case for most industrializing countries. If, however, this logic had been applied to China at the end of the 1970s, when the country began its continuing shift from a planned to a market economy, the result would have been far off the mark (Figure 1). Throughout most of the 1970s, the amount of energy China used to produce a unit of GDP rose, as expected. After 1977, though, energy intensity began to fall, even as GDP kept growing. If China had achieved Deng Xiaoping's stated goal of quadrupling per capita economic output between 1980 and 2000 at 1977 energy intensity, then the country would have consumed more than three times the amount of energy it actually did in 1999. China actually exceeded its growth targets ahead of schedule, with per capita GDP more than quadrupling and total GDP increasing by nearly a factor of six, while energy use only doubled—another broad target set by the government.

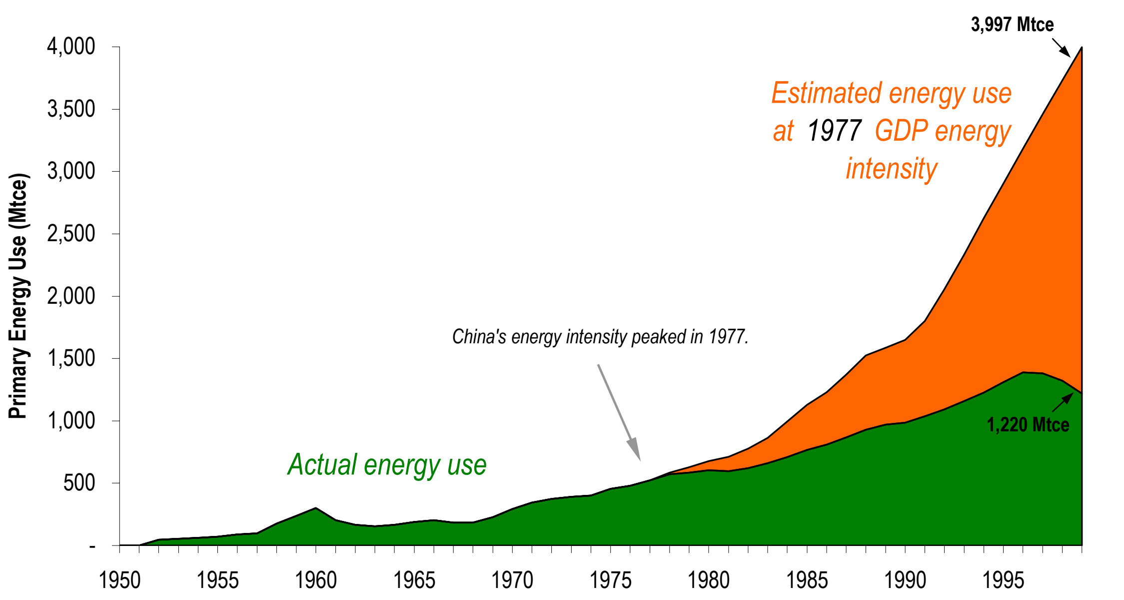


Figure 1. Actual Energy Use in China, and Calculated Energy Use at 1977 GDP Energy Intensity

It was widely recognized in China in the early 1980s that, aside from any other considerations, energy supply would not be able to expand as rapidly as the economic growth targets, and the nation would not be able to afford such massive imports. By the logic commonly used to forecast energy use in developing countries, however, the upper line in Figure 1 would have been an underestimate. Recognizing that following such simple thinking would not produce useful results, many researchers in China and elsewhere have followed a variety of approaches, from the simple to the sophisticated, that try to more realistically account for energy-economy interactions.

Since the Rio Earth Summit in 1992, at least five major collaborative studies on China's future energy use and carbon dioxide emissions have been published, not to mention a host of smaller-scale studies. Methods used to prepare scenarios of future energy use and CO_2 emissions in China include both engineering-economic, or "bottom-up" models, and macroeconomic or "top-down" models. While projections of energy use in China were prepared in the early and mid-1980s, the five major energy and carbon scenario studies reviewed for this report were primarily bottom-up models that examined policy and technology options for reducing greenhouse gas emissions and other environmental impacts (Table 1). The studies date from 1994 to 2000 and represent a range of greenhouse gas emissions forecasts out to 2020 and beyond. They include:

- National Response Strategy for Global Climate Change: People's Republic of China (*National Response Strategy*, 1994);
- China: Issues and Options in Greenhouse Gas Emissions Control (*Issues and Options*, 1994);
- Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China (*Environmental Considerations*, 1996);
- Asia Least-cost Greenhouse Gas Abatement Strategy: People's Republic of China (*ALGAS*, 1998); and
- China Climate Change Country Study (*China Country Study*, 1999).

Below we broadly compare the features of the five studies, then go into a more detailed summary of the studies, including assumptions and potential weaknesses, and an analysis of key results. In a subsequent section, we briefly touch on eight other studies published between 1993 and 2000. Collectively, the studies represent a substantial body of knowledge. Each takes a different approach, but deals with similar underlying forces so that significant comparisons can be made. A number of other studies prepared in 1980s and early 1990s are described schematically in Appendix 3.

Table 1. Selected Scenario Studies of Energy Use and Carbon Emissions in China

Scenario Study	Sponsor	Author	Year	Scenarios: Energy	Scenarios: Carbon	Time Period
Studies Reviewed in this Paper						
National Response Strategy for Global Climate Change: People's Republic of China	ADB	ANL, EWC, TU; implemented by SSTC	1994	X	X	1990-2050
China: Issues and Options in Greenhouse Gas Emissions Control	GEF	NEPA, SPC, UNDP, WB	1994	X	X	1990-2020
Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China	UNEP, NEPA	ERI, TU, NEPA, UNEP	1996	X	X	1990-2020
Asia Least-cost Greenhouse Gas Abatement Strategy: People's Republic of China	ADB, GEF, UNDP	ADB, SSTC	1998	X	X	1990-2020
China Climate Change Country Study	SSTC, US DOE	Research Team	1999	X	X	1990-2030
Other Studies						
Energy Development Analysis for China in 2050		former Ministry of Energy (China)	1993	X		1990-2050
China's Energy—Forecast to 2015	US DOE	LANL, PNNL	1996	X		1995-2015
World Energy Outlook	IEA	IEA	1998	X		1990-2020
China's Electric Power Options: An Analysis of Economic and Environmental Costs	W. Alton Jones	BECon, BMI, ERI	1998	X		1990-2020
China's Energy and Economy in the 21st Century		CASS	1999	X		2000-2050
Study on Long Term Energy Development Strategies of China		CMRI	1999	X		2000-2050
International Energy Outlook	EIA	EIA	1999	X		2000-2020
Developing Countries and Global Climate Change: Electric Power Options in China	Pew	BECon, ERI, PNNL	2000	X	X	1995-2015

N.B. See Appendix 1 for abbreviations.

Energy use is the source of 80% or more of carbon dioxide, the main anthropogenically generated greenhouse gas. Most greenhouse gas mitigation studies therefore focus on energy use, although some also analyze other greenhouse gases, emissions sources, and sinks. There are a range of actions that can take place, from no-regrets measures that can be taken at no or net negative economic cost, to those that require additional investment and commitment. The five studies that are the focus of this paper all prepared scenarios for future energy demand and supply, as well as future greenhouse gas emissions.[1] These baseline scenarios typically assumed continued improvements in technology and in energy supply structure, with assumptions about the future of China's economy and population that are basically in line with official plans and forecasts. The studies also prepared policy scenarios to estimate potential reductions compared to baseline energy use and carbon emissions.

The approaches and models used differed among the five studies, and in some cases, were tailored especially for the project. Some studies focused only on carbon dioxide emissions from energy production and (in some cases) other human activities, while other studies evaluated the overall impact of environmental pollutants. The studies all considered sectors separately, and divided some sectors (e.g., industry) into multiple subsectors. Most of the studies used 1990 as the base year for the scenarios, and looked out thirty to sixty years into the future (2020 to 2050). All the studies took historical and base-year data from the National Bureau of Statistics (*Guojia Tongjiju*, formerly translated as the State Statistical Bureau) and other official sources, or extrapolated from official data.

While some studies were more comprehensive than others, they each had sections devoted to some or all of the following topics: analytic methods and key factors to include in a scenario model; historical and potential future trends in energy supply and end-use technology; inventories of greenhouse gas sources and sinks; key factors affecting energy demand; future policy and technology options; environmental and social ramifications of energy use, including the effect of climate change on China; costs and other factors affecting implementation of mitigation options; and the role and obligations of the international community.

The earliest two studies, funded by ADB (*National Response Strategy*) and the World Bank and Global Environment Facility (*Issues and Options*), were undertaken at about the same time (1992-1994) and followed similar approaches. The methods for estimating greenhouse emissions were based on those recommended at the OECD Paris Expert Conference in 1991 (OECD, 1991). Inventories of carbon dioxide emissions from fuel combustion were calculated from energy use data collected from the *Energy Statistical Yearbook of China 1991* (SSB, 1991).

The purposes of the studies were wide-ranging, but tended to focus on identifying effective policy and investment responses from the Chinese government and (to a lesser extent) international aid organizations and governments. In addition, the studies universally support the need for a cleaner carbon future. Some of these reports were parts of series covering Asia, and so they were written in a regional context, rather than from a purely national perspective.

[1] While EIA's *International Energy Outlook* does not project carbon dioxide emissions, it is included for comparison because it is a widely circulated annual report that has the potential to strongly influence the views of many people on China's future greenhouse gas emissions. Emissions were calculated using emissions factors from the *China Country Study*. See Appendix 2 for the method used.

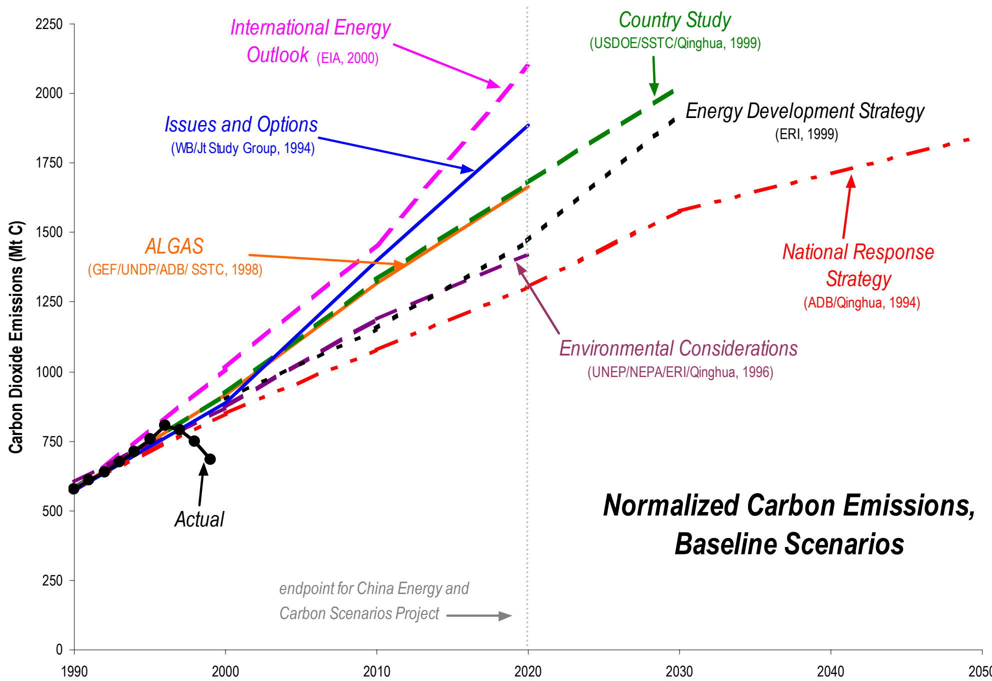


Figure 2. Baseline Scenarios of Primary Energy Use for China

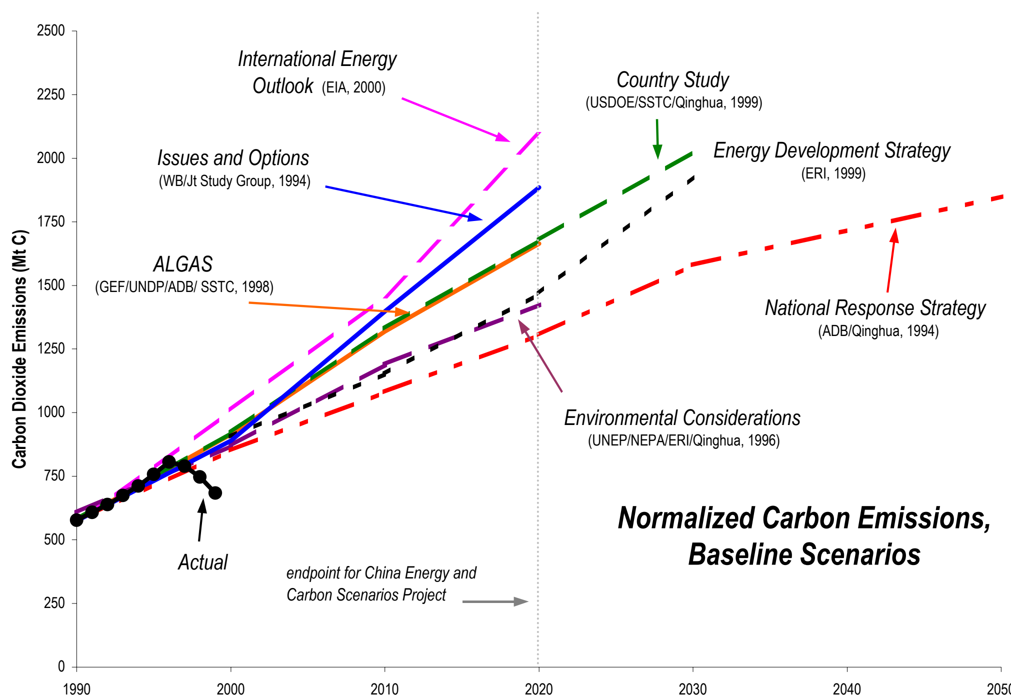


Figure 3. Baseline Scenarios of Carbon Dioxide Emissions for China (Normalized)

Figure 2 and Figure 3 compare the baseline scenarios of primary energy use (excluding biomass fuels) and carbon dioxide emissions of the five studies examined in this report, as well as a recent and widely read study prepared by the Energy Research Institute. Actual energy use and carbon dioxide emissions from 1990 to 1999 are also included for comparison. In Figure 3 the carbon dioxide emissions calculated by each study were normalized by using a common set of emissions factors, i.e., those used in the *China Country Study* (see Appendix 2).[2] The highest baseline energy use and carbon emissions projection for 2020 (*International Energy Outlook*) is about 60% higher than the lowest (*Environmental Considerations*). Counter to expectations, the highest projection is also the most recent, and the lowest projection is not from the earliest study. The reasons for these differences among baseline scenarios will become evident in the detailed descriptions of the scenarios below.

Despite differences among the baseline scenarios, one of the most striking characteristics of the collection is their similarity. While each has slightly varying assumptions about economic and population growth, as well as rates of change in energy supply structure and efficiency of end use technology, they all follow the same type of curve displaying decelerating growth. Some of the studies also include variant scenarios, which use alternate assumptions about future variations in key variables, such as economic growth. However, none go so far as to create strategic scenarios of the type that the Shell Scenarios Group produces, which can introduce fluctuations in key variables in response to future events that might reasonably be expected, e.g., recessions followed by periods of recovery. While such events cannot be predicted with certainty, creating such scenarios is useful in evaluating the robustness of policy choices under a variety of possible future conditions.

None of the studies accounted for the recent rather spectacular fall in China's energy use—a point that argues strongly for a revised analysis of future energy use and pollutant emissions. In fact, not even the most aggressive policy scenario comes close to actual energy use in the late 1990s (Figure 4). Compared to interpolated carbon dioxide emissions in 1999 in one of the scenario studies that falls in the middle of the range of the scenario studies (*China Country Study*), actual carbon dioxide emissions were nearly 200 MtC below the baseline and almost 120 MtC below the most aggressive policy scenario (Figure 5). Even if energy use were to begin rising again in the near future at a rate comparable to that projected in the *China Country Study*, it would likely be about 2010 before China's carbon dioxide emissions regained the peak level of 1996. We return to the reasons for conducting a new scenarios study at the end of this report, after reviewing the previous studies.

[2] Note that the relative differences between scenarios varies slightly between the two figures. This is due mainly to differences in fuel structure, since different fuels have different carbon emissions factors. A scenario that posits a higher share of coal will exhibit higher carbon emissions than a scenario that posits the same quantity of total energy consumption, but a lower share of coal compared to less cabon-intensive fossil fuels. See Figure 6 below.

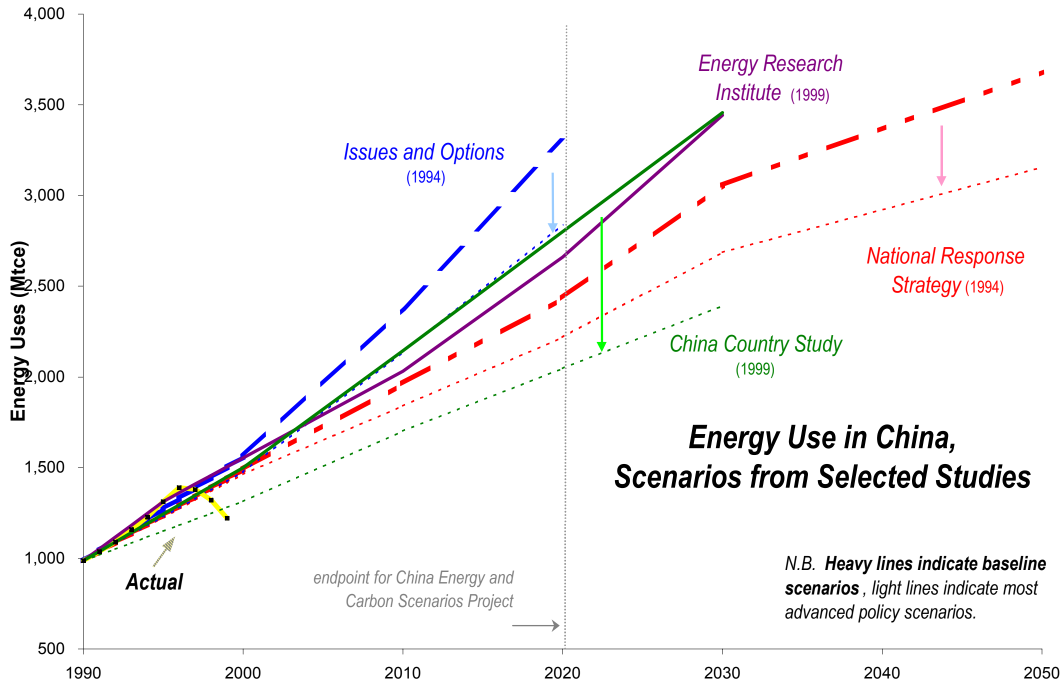


Figure 4. Selected Baseline and Policy Scenarios of Energy Use

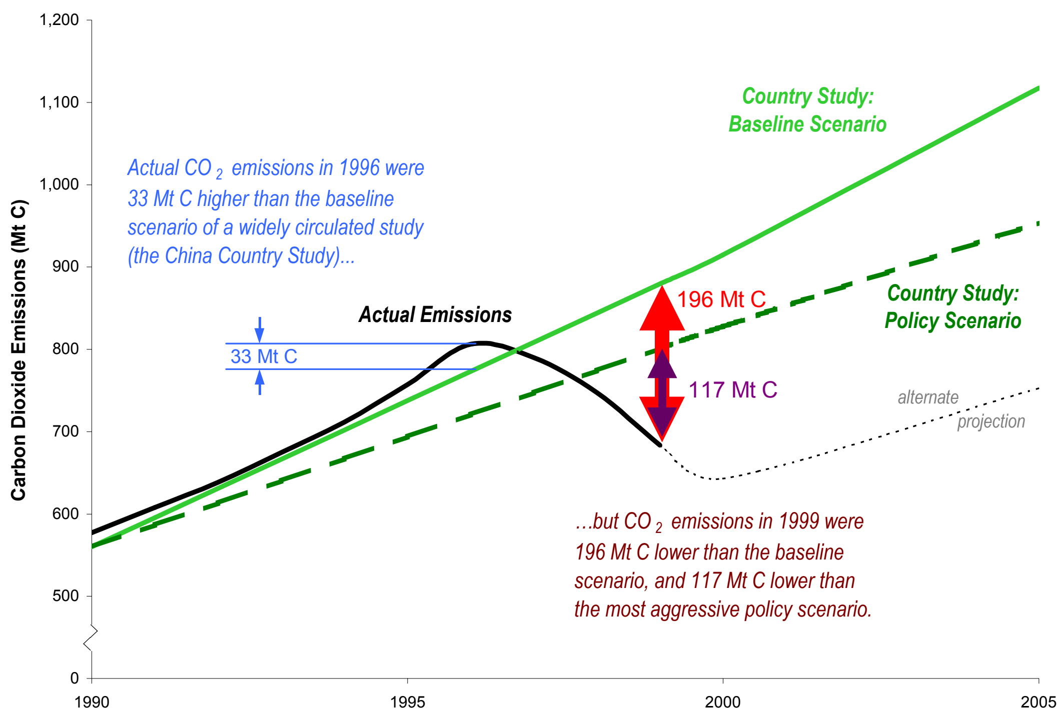


Figure 5. Actual Energy Use Compared to the *China Country Study* Baseline and Policy Scenarios

Review of Previous Scenarios Studies

In the following sections, we present capsule descriptions of the five major studies in chronological order, reviewing the background and objectives of the studies, the methods used, and the assumptions and results. We then briefly cover eight additional scenarios studies, and end the section with a summary comparison.

NATIONAL RESPONSE STRATEGY FOR GLOBAL CLIMATE CHANGE: PEOPLE'S REPUBLIC OF CHINA

Background and Objectives

The *National Response Strategy* (East-West Center, *et al*., 1994) was funded by the Asian Development Bank (ADB) and implemented by the State Science and Technology Commission of China (SSTC). The study was prepared jointly by international and Chinese experts from the East-West Center, Argonne National Laboratory, and Tsinghua University. Climate change mitigation options in a range of sectors were identified, and energy demand and supply projections were modeled under various scenarios. The main objective of this study was to develop and evaluate measures in China that could address climate change concerns.

Estimates were made of principle anthropogenic greenhouse gas emissions in 1990, including CO_2, CH_4, N_2O, and CFCs. In addition, projections of future CO_2 emissions extend until 2050. This is the longest projection of the studies reviewed in this report. Measures to reduce future CO_2 emissions were identified and both the costs and potential emissions reductions were calculated. Some methane reduction measures were discussed and China's vulnerability to climate change was analyzed.

Methods

The study included three realistic scenarios, which were defined by a combination of policy options and variable economic growth rates: BAU/low growth, policy/low growth, and accelerated policy/high growth. Originally, BAU/low, policy/low, BAU/high, and policy/high scenarios were run. However, the present energy supply system suggested that energy supply in China probably could not exceed 4,000 Mtce (1 metric ton of standard coal equivalent equals 29.31 GJ) by 2020. Therefore, the BAU/high scenario and the policy/high scenario were not likely. An additional scenario, accelerated policy/high growth, was developed.

Energy end-use demand was modeled using sectoral technical/economic analysis. Multiple sectors were included from the energy demand side: industry, transportation, agriculture, service, and residential, with data coming from the State Statistical Bureau. The macro-economic computer models were developed at the Institute of Nuclear Energy Technology (INET) at Tsinghua University and Argonne National Laboratory (ANL).

Assumptions and Results

The assumptions used in *National Response Strategy* and the results of the scenarios are summarized in Table 2. (The population, urbanization, economic growth, industrial structure assumptions used in the five studies are compared in Tables 10-12.)

Table 2. Assumptions and Results, *National Response Strategy*

	Unit	1990	2000	2010	2020
ASSUMPTIONS					
Total population	million	1,140	1,294		1,455
Proportion in cities and towns	%	26	32		44
GDP	billion 1990 yuan	1,769	3,818		10,131
GDP growth					
Baseline and Policy-Low	% p.a.	8.0	5.5	6.0	
Policy-High	% p.a.	8.5	7.0	6.0	
Sectoral structure of GDP					
Agriculture	%	28	23		15
Industry	%	44	44		42
Services	%	28	33		43
RESULTS					
Baseline					
Total Primary Energy	Mtce	987	1491		2434
Carbon dioxide emissions	MtC	626	907		1354
Policy-Low					
Total Primary Energy	Mtce		1464		2218
Carbon dioxide emissions	MtC		888		1179
Policy-High					
Total Primary Energy	Mtce		1495		2518
Carbon dioxide emissions	MtC		904		1335

N.B. Carbon dioxide emissions are as reported in the study, and differ slightly from the normalized values used in the figures in this report.

Table 3 Summary of Scenarios to 2050, *National Response Strategy*

	Business-as-Usual	**Policy**
Low Economic Growth	GDP= 24.6 tY Energy Demand= 3.7 btce **CO_2 emissions= 1,918 MtC**	GDP= 24.6 tY Energy Demand= 3.2 btce **CO_2 emissions= 1,467 MtC**
High Economic Growth	GDP= 52.8 tY Energy Demand= 5.4 btce	GDP= 52.8 tY Energy Demand= 4.3 btce

In 1990, GDP= 1.8 thousand Yuan (tY) and Energy Demand= 1.0 billion tons of coal equivalent (btce)

The difference between following the BAU and the policy options (at low growth) is 451 MtC out of 1,918 MtC in the baseline scenario in 2050, implying a great reduction potential for carbon emissions. The accelerated policy/high growth scenario mimics the path of the BAU/low growth scenario only until 2020. Afterwards, a reduction in carbon emissions is projected.

China: Issues and Options in Greenhouse Gas Emissions Control

Background and Objectives

Issues and Options (NEPA *et al.*, 1994) is an extensive macroeconomic and microeconomic analysis study which compiled a greenhouse gas emission inventory, developed scenarios for the future growth of greenhouse gases, and identified priority areas for reductions of greenhouse gas emissions. This United Nations Development Programme (UNDP) technical assistance study was prepared jointly by the Chinese government and the World Bank. In China, the National Environmental Protection Agency[3] managed the research. A main objective of the report was to identify and evaluate low-cost options for greenhouse gas emissions reductions that China can implement in the short to medium term, or by the year 2010.

The study was motivated by the potentially disastrous impacts of greenhouse gas emissions on global climate. *Issues and Options* prioritized measures for controlling greenhouse gas emissions through energy efficiency, alternative energy (renewables and nuclear power), forestry, and agriculture, with a strong emphasis on economic reform and "no-regrets" options, and development of low-carbon-intensive energy technologies. Priority policy, investment, and technical assistance areas were identified. The study laid the groundwork for proposals that eventually led to a variety of energy efficiency and renewable energy projects supported by the World Bank, the Global Environment Facility, and other organizations.

Methods

On the energy demand side, several energy-intensive industrial sectors were covered in the study. These included steel, aluminum, ammonia, caustic soda, cement, pulp and paper, and textiles. Carbon dioxide from energy consumption was estimated from a model, as well as carbon dioxide emissions from cement and methane emissions from rice cultivation, coal mining, and animal husbandry. In addition, local pollutant emissions such as total suspended particulates and sulfur dioxide were included in the analysis. Baseline, high-growth, and low-growth scenarios were generated with a China Greenhouse Gas Model over a thirty year period (1990-2020).

The framework for analysis was formed via a logical progression of steps. First, a greenhouse gas inventory was prepared, future emissions trends were predicted, and then areas for reduction were identified and analyzed. A China Greenhouse Gas Model was used to simulate economic growth, structural change, energy consumption, and the resulting emissions of greenhouse gases and selected local air pollutants within China. The China greenhouse gas model had four components: a macroeconomic model, an input-output model, energy coefficients, and emissions coefficients. The model was based on a model originally built by a group from Stanford University, University of Pennsylvania, and the Chinese Academy of Social Sciences. A macro model fed to an input-output table, which gave energy consumption levels, which were then converted to greenhouse gas emissions using a set of emissions factors for each fuel. The impacts of alternative energy, afforestation, and agricultural programs were evaluated separately and the results were incorporated into the China greenhouse gas model.

Assumptions and Results

The baseline scenario was based on China's development program that was current at the time of the study. Basic socioeconomic assumptions in this study were in line with those used in the other studies. Assumptions about population growth were virtually the same (Table 10). Baseline

[3] Now the State Environmental Protection Administration (SEPA).

estimates of GDP growth rates, on the other hand, were at the upper range of the studies, i.e., 8% per year from 2000 to 2010, and 6.5% per year from 2010 to 2020, while policy scenario estimated were on the middle to low end of the ranges in the study, i.e., 6.5% per year and 5.0% per year respectively (Table 11). The structure of economic output was projected to be weighted more heavily towards industry than in any of the other studies, with industry retaining a 48% share of GDP in 2020 (Table 12).

Table 4. Assumptions and Results, *Issues and Options*

	Unit	1990	2000	2010	2020
ASSUMPTIONS					
Total population	million	1,140	1,280		1,447
Proportion in cities and towns	%	26	31		42
GDP	billion 1990 yuan	1,769	3,818		10,131
GDP growth					
Baseline and High-Efficiency	% p.a.	9.5	8.0	6.5	
Slow-Growth	% p.a.	8.0	6.5	5.0	
Sectoral structure of GDP					
Agriculture	%	28	16		7
Industry	%	44	50		48
Services	%	28	34		45
RESULTS					
Baseline					
Total Primary Energy	Mtce	987	1,560	2,380	3,300
Carbon dioxide emissions	MtC	801	1,201	1,795	2,398
High-Efficiency					
Total Primary Energy	Mtce		1,474		2,841
Carbon dioxide emissions	MtC		1,064		1,590

N.B. Carbon dioxide emissions are as reported in the study, and differ slightly from the normalized values used in the figures in this report.

Extensive studies of technology trends and options in major energy-consuming sectors, including detailed technical and economic evaluations of key industrial energy-efficiency and power-generation measures, were performed. This information was used to make projections of future energy use in sectors, and provides important background for other studies that take a bottom-up approach, including the present project.

One of the main conclusions of this report was that if China were to follow the recommended ‘no-regrets’ options, the future increase in China’s greenhouse gas emissions would be a doubling between 1990 and 2020 rather than a tripling. In other words, greenhouse gas emissions in 2020 would be 1590 MtC rather than 2398 MtC. The impacts of various ‘no-regrets’ options on greenhouse gas emissions reduction are summarized in Table 5**.** *Issues and Options* identified four priority project areas for mitigation, with specific actions. These areas are: energy efficiency, alternative energy, forestry measures (e.g., afforestation), and agricultural measures (e.g., reduction of methane emissions from rice cultivation and livestock).

Table 5. Potential for Reducing Greenhouse Gas Emissions in China, *Issues and Options*

	Reductions in emissions relative to baseline (MtC)
Baseline Greenhouse Gas Scenario	2,398
High Energy Efficiency	-330
Alternative Energy (high scenario)	-237
Afforestation (high scenario)	-221
Agriculture	-15 to –25
Total Potential Greenhouse Gas Abatement	-808

The policy scenarios led to a larger drops in greenhouse gases than in energy use because the reductions in emissions were largely related to changes in the structure of energy supply, i.e., greater use of low-carbon fuels, rather than a decrease in absolute energy consumption. Conclusions point to "no-regrets" measures as the most effective way to mitigate greenhouse gases.

Aside from the Energy Information Administration's *International Energy Outlook*, both the baseline and policy scenarios produced by this study were markedly higher than those for subsequent studies. The use of generic emissions coefficients instead of China-specific, industry-specific and region-specific figures contributed to this difference, but the difference remains significant, even when emissions are normalized.

INCORPORATION OF ENVIRONMENTAL CONSIDERATIONS IN ENERGY PLANNING IN THE PEOPLE'S REPUBLIC OF CHINA

Background and Objectives

Environmental Considerations (UNEP *et al*., 1996) identifies policy recommendations for supporting an energy system that is more compatible with sustainable development. This project was jointly funded and executed by UNEP and NEPA of China. In this project, the range of environmental indicators was broader than in the other studies, included sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide, and particulates. There was thus a focus on human health and non-climate change related environmental damages that was not present in the other studies.

This study included both a long-term and a short-term objective, though both are related to improving energy policy in China. The long-term aim of the report was to incorporate environmental criteria into energy policy and planning, while the short-term goal was to promote national policy that would mitigate environmental impacts of energy-related activities. Building national institutional capacity, and enhancing policies for energy efficiency and renewable energy were cited as additional goals.

Methods

This study used a bottom-up methodology because a main purpose of the study is to examine the economic and environmental implications of energy policies. The LEAP/EDB model accounting framework was used, rather than an optimization approach. LEAP software, developed by Stockholm Environment Institute (Boston), incorporates an accounting framework with cross-sectoral analysis and an energy planning system. The base year was 1990, with forecast years of

2000, 2010, and 2020. Outputs included energy demand and emissions of the criteria pollutants listed above.

A baseline scenario, reflecting official policies and forecasts of macroeconomic, demographic, and energy sector indicators from 1990 until 2020, was first established. Sectors included: households, agriculture, iron and steel, building materials, chemicals, nonferrous metals, light industry, machinery and electronics, transportation, coal mining, oil and natural gas, power industry, and services. Two policy scenarios, Scenario I and Scenario II, included some and all, respectively, of the mitigation policies recommended in the study. Cost-benefit analysis was applied to the policy scenarios.

Assumptions and Results

Projections of economic growth were in accordance with the economic growth targets of the Eighth Five-Year Plan and longer term plans. The baseline scenario and the two policy scenarios all use identical projections of socioeconomic variables (Table 8). The figures at the beginning of the report showed that, along with *National Response Strategy*, this study had one of the lowest baseline energy and carbon emissions scenarios. The two policy scenarios resulted in energy use at 9% and 13% below baseline in 2020.

A Business-as-Usual scenario compared to Enhanced Scenario I and Enhanced Scenario II for CO_2 emissions shows slower growth for both policy scenarios. In 2020, Enhanced Scenario I shows an 8.5% reduction in CO_2 emissions from BAU, while the more comprehensive mitigation scenario, Enhanced Scenario II, shows a 12.81% reduction from BAU. In both cases, the results of mitigation measures are more apparent in the long-term future. Table 7 summarizes the reduction of pollutant emissions under Enhanced Scenario I and II.

Table 6. Assumptions and Results, *Environmental Considerations*

	Unit	1990	2000	2010	2020
ASSUMPTIONS					
Total population	million	1,140	1,294		1,450
Proportion in cities and towns	%	26	31		45
GDP	billion 1990 yuan	1,768	4,185	8,625	15,445
GDP growth	% p.a.	9.0	7.5	6.0	
Sectoral structure of GDP					
Agriculture	%	28	18		9
Industry	%	44	45		41
Services	%	28	36		50
RESULTS					
Baseline					
Total Primary Energy	Mtce	987	1,498	2,053	2,576
Carbon dioxide emissions	MtC	647	1,027	1,369	1,636
Policy I					
Total Primary Energy	Mtce		1,432	1,920	2,356
Carbon dioxide emissions	MtC		982	1,280	1,496
Policy II					
Total Primary Energy	Mtce		1,432	1,881	2,245
Carbon dioxide emissions	MtC		982	1,254	1,426

N.B. Carbon dioxide emissions are as reported in the study, and differ slightly from the normalized values used in the figures in this report.

Table 7 The Reduction of Pollutant Emissions for Scenario I and Scenario II, over BAU, *Environmental Considerations*

		2000			2010			2020		
		Base	**S I**	**S II**	**Base**	**S I**	**S II**	**Base**	**S I**	**S II**
CO_2	Emissions (MtC)	1026	982	982	1369	1280	1254	1635	1496	1426
	Reduction (%)		*4.4%*	*4.3%*		*6.5%*	*8.4%*		*8.5%*	*12.8%*
CO	Emissions (MtC)	50.4	48.4	47.3	70.4	66.6	65.4	85.8	81.1	79.6
	Reduction (%)		*4.1%*	*6.2%*		*5.5%*	*7.1%*		*5.4%*	*7.2%*
NO_x	Emissions (MtC)	15.6	15.1	15.2	21.9	21.0	20.6	28.4	26.4	25.2
	Reduction (%)		*3.0%*	*2.4%*		*4.4%*	*6.0%*		*7.0%*	*11.1%*
SO_2	Emissions (MtC)	23.8	20.8	20.5	31.1	25.0	23.5	35.5	25.9	22.7
	Reduction (%)		*12.4%*	*14.1%*		*19.5%*	*24.4%*		*27.2%*	*36.0%*
PM	Emissions (MtC)	18.0	16.3	16.3	24.6	21.1	20.3	29.6	23.6	21.4
	Reduction (%)		*9.5%*	*9.3%*		*14.3%*	*17.4%*		*20.5%*	*27.9%*

The enhanced environmental characteristics come primarily from a sharp decrease in coal consumption, and an increase of hydropower, nuclear power, and biomass. Carbon dioxide emissions decrease by almost 13% compared to the baseline in the enhanced Scenario II, in 2020. This mitigation comes with significant reduction in other pollutants.

In addition to policy recommendations, this study identified factors that are necessary to overcome barriers to policy implementation. The cooperative process of completing this report led to an improved understanding of relevant decision-making organizations and actors, and their potentially conflicting objectives and strategies.

ASIA LEAST-COST GREENHOUSE GAS ABATEMENT STRATEGY: PEOPLE'S REPUBLIC OF CHINA

Background and Objectives

ALGAS (ADB, 1998) was executed by the Asian Development Bank (ADB) and mainly funded by the Global Environment Facility (GEF) and the United Nations Development Program (UNDP). This study was part of a regional effort to aid countries in preparing greenhouse gas abatement strategies. The main objective of the report was to identify and evaluate low-cost options for greenhouse gas reduction that China can implement in the short term, or by the year 2010. It is one of a series of reports in 12 Asian countries which, when added, contain more than half of the world's population. A team of national and international experts conducted the two-year investigation. In China, the government was involved through the Department of Science and Technology for Social Development of the State Science and Technology Commission.[4]

[4] Now the Ministry of Science and Technology (MOST).

The study produced estimates of emissions of greenhouse gas in 1990, a projection of greenhouse gas emissions to 2020, an analysis of options for greenhouse gas abatement in the energy sector, forestry and land-use sector, and agriculture sector, and detailed case studies of two technical assistance programs and seven investment projects. Least-cost greenhouse gas abatement strategies in China were identified, including improving energy efficiency, developing alternative energy, enforcing afforestation, and decreasing methane emissions from agriculture. In contrast to other climate change research, this study focuses on greenhouse gas emissions mitigation in non-industrial sectors rather than the industrial and power sectors.

Methods

This study used the INET Energy System Optimization Model, a policy analysis optimization model based on the assessment of energy technology and policy options, and developed by Tsinghua University's Institute for Nuclear Energy Technology.[5] Sub-models were an energy demand analysis model and an energy technology optimization model. The INET model is similar to the MARKAL model in function but is more representative of the centrally planned system that used to exist in China. It was used to project economic development, energy supply, energy demand, and greenhouse gas emissions. Since the model cannot analyze the effect of greenhouse gas abatement strategies on economic growth, this study used Cost of Emissions Reduction Initiative (CERI) curves to analyze the cost of mitigating greenhouse gases. The CERI curve represents the cumulative supply curve for all greenhouse gas abatement measures in a particular sector, allowing identification of a set of "least-cost" options. Finally, the Analytical Hierarchy Process was used to quantitatively and qualitatively assess the options.

Assumptions and Results

Three scenarios, a baseline scenario and two abatement scenarios were produced. The three scenarios used identical assumptions of population, GDP growth, and industrial output shifts (Table 8). They differed in their assumptions regarding energy policy, and technical improvements in energy supply, conversion, and utilization. Specific options for greenhouse gas reduction were identified, and then the cost of reduction was examined in greater detail. Priority policy, investment, and technical assistance areas were identified.

As seen in Figure 2, the baseline energy and carbon emissions scenarios for *ALGAS* fell roughly in the middle of the other scenarios. The Abatement I and Abatement II scenarios resulted in energy use 13% and 18% below baseline in 2020, respectively (Table 8). Because of fuel structure changes (i.e., more rapid penetration of less carbon-intensive fuels) in the two abatement scenarios, carbon emissions fell even more rapidly than energy use (15% and 22% respectively).

[5] This model has been used in a number of other studies, and was one of several used in the *China Country Study*.

Table 8. Assumptions and Results, *ALGAS*

	Unit	1990	2000	2010	2020
ASSUMPTIONS					
Total population	million	1,140	1,300	1,390	1,500
Proportion in cities and towns	%	26	34	42	51
GDP	billion 1990 $	370	960	2,070	3,900
GDP per capita	$	325	740	1,490	2,600
GDP growth	% p.a.	10	8	6.5	
Sectoral structure of GDP					
Agriculture	%	28	23	18	14
Industry	%	44	43	42	39
Services	%	28	34	40	47
RESULTS					
Baseline					
Total Primary Energy	Mtce	987	1,562	2,235	2,920
Carbon dioxide emissions	MtC	567	915	1,320	1,695
Abatement I					
Total Primary Energy	Mtce		1,509		2,553
Carbon dioxide emissions	MtC		865		1,439
Abatement II					
Total Primary Energy	Mtce		1,456		2,394
Carbon dioxide emissions	MtC		817		1,318

N.B. Carbon dioxide emissions are as reported in the study, and differ slightly from the normalized values used in the figures in this report.

CHINA CLIMATE CHANGE COUNTRY STUDY

Background and Objectives

The *China Country Study* (Research Team of China Climate Change Study, 1999) was supported by the Department of Energy of the United States and the State Science and Technology Commission of China. The project was started in October 1994 in an effort to investigate scientific and policy issues related to climate change in China. The International Workshop on Greenhouse Gas Mitigation Technology (Beijing, November 1996), which attracted participants from 33 countries, was based on research outputs from the project. The final report was published in April 1999. The report also assesses ecological as well as social-economic impacts of climate change on China.

The study had four objectives, including: (1) identification of greenhouse gas sources and sinks, and preliminary compilation of an inventory of major greenhouse gases; (2) assessment of climate change impacts and studies of adaptive response policies; (3) identification and integration of technological options for greenhouse gas mitigation and analysis of socioeconomic and environmental implications; and (4) socioeconomic evaluation of climate change response policies, including an integrated option assessment for future greenhouse gas emissions.

This report focused on greenhouse gas emissions and climate change, rather than broader environmental or energy areas such as air quality, energy supply and demand in the future, and the impact of GDP growth on global climate change.

Methods

This study used two calculation methods to estimate greenhouse gas emissions from energy activities, i.e. the detailed fuel classification method and the detailed technology classification method. Emissions from industrial processing, agricultural sectors, and forests were estimated. In addition, energy-related mitigation technologies such as energy efficiency technologies, energy substitution, and priority mitigation technologies were evaluated

The *China Country Study* calculated carbon dioxide emissions from energy consumption, carbon dioxide emissions caused by deforestation and cement production, as well as methane emissions from coal mining, rice fields, livestock, landfills, wastewater treatment, and waste incineration. The sectors covered in the analysis of energy consumption included agriculture, industry, transportation, services, and households. Two models developed by the Institute of Nuclear Energy Technology (INET), Tsinghua University were used to prepare scenarios of energy demand and supply. A bottom-up, simulation approach was used for the demand side, i.e., the End-use Energy Demand Analysis Model. Outputs from this model were fed into the Energy System Optimization Model to determine a least-cost energy supply mix to meet demand. Carbon dioxide emissions were then calculated for 2000, 2010, and 2030.

Three different models were used to assess socioeconomic impacts of climate change, including costs of mitigation. Two models were used by the Energy Research Institute. One, ERI-SGM, is a computable general equilibrium (CGE) model that can be used to examine such issues as the impact of a carbon tax.. The other, ERI-AIM, was a complex, regional bottom-up model that is intended to simulate linkages between technology options, energy efficiency, energy demand, socioeconomic factors, and carbon emissions. The third model was Tsinghua's coupled I/O-INET model, with a CGE model component based on China's national input-output table feeding into the Energy System Optimization Model described above. Results of analysis using these models were not presented in the *China Country Study* report.

Assumptions and Results

The Country Study compiled an inventory of greenhouse gases in China, assess potential climate change impacts, and evaluate technological as well as socioeconomic response policies. It was estimated that 547 to 560 MtC of carbon dioxide came from energy activities in 1990, accounting for over 96% of total carbon dioxide emissions. Nearly 12 Mt of methane emissions came from energy activities. The study included three scenarios, a baseline scenario, a policy-scenario that used the same basic socioeconomic assumptions, and a low-policy scenario that assumed lower economic growth.

Like *ALGAS*, the baseline energy and carbon emissions scenarios for the *Country Study* were in the middle of the range set by the other scenarios (Figure 2). The policy and low-policy scenarios resulted in energy use 19% and 31% below baseline in the end year 2030, respectively (Table 9). Changes in fuel supply structure in the two policy scenarios resulted in even greater carbon emissions reductions, 30% and 39% respectively.

Table 9. Assumptions and Results, *Country Study*

	Unit	1990	2000	2010	2030
ASSUMPTIONS					
Total population	million	1,143	1,294	1,386	1,560
Proportion urban population	%	26	34	42	58
GDP	billion 1990 yuan	1,768	4,586	9,901	31,747
GDP per capita	$	324	741	1,495	4,258
GDP growth					
Baseline and Policy	% p.a.	10	8	6	
Low-Policy	% p.a.	9	7	5	
Sectoral structure of GDP					
Agriculture	%	28	23	18	14
Industry	%	44	43	42	39
Services	%	28	34	40	47
RESULTS					
Baseline					
Total Primary Energy	Mtce	943	1,500	2,144	3,458
Carbon dioxide emissions	MtC	560	915	1,320	1,981
Policy					
Total Primary Energy	Mtce	943	1,376	1,854	2,784
Carbon dioxide emissions	MtC	560	828	1,080	1,382
Low-Policy					
Total Primary Energy	Mtce	943	1,314	1,703	2,393
Carbon dioxide emissions	MtC	560	786	989	1,211

SUMMARY AND COMPARISON OF ASSUMPTIONS AND RESULTS

In this section, we compare the five major studies described above.

Objectives

All but one of these studies was aimed at examining China's future greenhouse gas emissions and ways of mitigating them. The exception, *National Considerations*, looked at climate change as one of a broader set of environmental problems facing China. Since energy is the main source of greenhouse gases, the studies devoted large sections to inventorying carbon dioxide emissions from fossil fuel combustion, developing baseline scenarios of future energy use, and analyzing technical measures to reduce energy-related carbon emissions, as well as policies to promote adoption of those technical measures.

All studies concluded with recommendations for future reductions through policy, technology, and foreign investment recommendations. Rather than simply being an analysis of what would occur in China under different circumstances, results from the models were used as justification for specific policy measures.

Methods

These studies used a combination of top-down and bottom-up approaches, with many using two or more models, and some studies using the some of the same models as other studies. Some of the studies, e.g., *Issues and Options* and the *China Country Study* devoted considerable effort to characterizing the potential of individual technical measures to improve energy efficiency, ncluding costs of those measures, and potential reductions in carbon emissions. This very specific

bottom-up information was often used as the basis for estimating efficiency improvements used in models.
One perennial difficulty in scenarios studies is estimating the impact of policy-induced technical changes throughout the economy. The use of an input-output model, such as used in the *Issues and Options* study, has the advantage of being able to account for interactions between economic sectors, something that other approaches, such as simulation models, cannot handle automatically. On the other hand, input-output models rely on a very large set of coefficients that are very closely related to the state of technology at the time period for which a model is constructed. Accounting for changes in these coefficients over time is fraught with difficulty, and such models are typically better at evaluating changes over short time scales, rather than spans of several decades, as is needed for scenarios studies. Simulation models have an advantage in this area, as they are better able to explicitly account for the technical relationship between outputs of goods and services and the energy needed to provide them. The level of technical detail that went into preparing the *Issues and Options* estimates of future changes in energy intensity of key processes, however, seems to be closer than any of the other studies to the kind of detail that is planned for the Scenarios Project.

Some of the studies included both baseline and business-as-usual (BAU) scenarios, which are not directly comparable. A BAU scenario often assumes that trends from the present will continue unchanged, and future policy measures are disregarded. The baseline scenarios typically attempted to incorporate changes that will come with economic development and continuation of policy directions current at the time of the study.

Assumptions and Results

All of the major studies included greenhouse gas emission inventories for China in 1990. The greenhouse gas emissions inventories were not identical, but fell within about 20% of each other. Emissions were normalized for this paper, as explained in Appendix 2.

Table 10 Population Assumptions for Studies

	Population (million)			Urban Population (%)		
	1990	2000	2020	1990	2000	2020
Issues and Options	--	1280	1447	--	31.0	42.0
National Response Strategy	--	1294	1455	--	32.4	44.4
Environmental Considerations	--	1294	1450	--	31.4	44.8
ALGAS	1,140	1,300	1,500	26	34	51
Country Study	1,143	1,294	1,386/1,560*	26.4	34.4	42.4/58.4**

* 2010/2030.

Table 11 GDP Growth Rates (percent average annual growth)

	1990-2000	2000-2010	2010-2020
Issues and Options-Baseline and High Efficiency	9.5	8.0	6.5
Issues and Options -Slow Growth	8.0	6.5	5.0
National Response Strategy –High	8.5	7.0	6.0
National Response Strategy –Baseline and Low	8.0	5.5	6.0
Environmental Considerations	9.0	7.5	6.0
ALGAS-Baseline	10	8	6.5
Country Study –Baseline and Policy	10	8.0	6.0 *(2010-2030)*
Country Study -Low-Policy	9.0	7.0	5.0

Projected changes in economic structure varied more widely, however, with some assuming a more rapid shift from industry to services than others (Table 12). Some of the alternate and policy scenarios were run using different economic and energy consumption parameters, e.g., assuming slower economic growth (Table 13). For many of the studies, the projections used in the scenarios of changes in energy efficiency within sectors and of key energy-using processes (e.g., power generation and steel manufacturing) were not explicitly given, and cannot be directly compared, but, in general, baseline scenarios assumed continued improvements in energy efficiency due to technological improvements, changes in output structure, and equipment turnover.

Table 12 Distribution of GDP by Sector (percent)

	2000			2020		
	Agriculture	Industry	Services	Agriculture	Industry	Services
Issues and Options –Baseline	16	50	34	7	48	45
National Response Strategy	23	44	33	15	42	43
Environmental Considerations	18	45	36	9	41	50
ALGAS	23	43	34	14	39	47
Country Study	23	43	34	18/14*	42/39*	40/47*

* 2010/2030.

Table 13 Economic Growth Assumptions and Energy Demand Reductions for Policy Scenarios

	Scenario	Economic Growth	Reduction from Baseline Energy Demand in End Year
Issues and Options	Baseline	Baseline	
	Slow growth	Low Growth	
	High efficiency	Baseline	
National Response Strategy	Accelerated Policy	High Growth	
	BAU	Low Growth	
	Policy	Low Growth	
Environmental Considerations	BAU	Baseline	
	Enhanced Environmental Scenario I	Baseline	9%
	Enhanced Environmental Scenario II	Baseline	13%
ALGAS	Baseline	Baseline	
	Abatement I	Baseline	13%
	Abatement II	Baseline	18%
Country Study	Baseline	Baseline	
	Policy Scenario	Baseline	19%
	Low-Policy scenario	Low Growth	31%

Most of these studies worked from baselines that paralleled official plans and projections for major variables, such as population, economic growth, economic structure, and output of key products and services. Assumptions about population were almost identical, except for *ALGAS*, which assumed more rapid urbanization than the other studies Table 10). Assumed rates of GDP growth were within one percentage point for the baseline scenarios, and the range between baseline and policy scenarios within studies was never more than 1.5 percentage points (Table 11). The closeness of these assumptions helps account for the basic similarity of the studies.

Energy use and carbon dioxide emissions under the baseline scenarios and some of the policy scenarios of the various studies have already been compared to each other and to actual energy use and emissions above and discussed (Figure 2 through Figure 5). Some of the differences between the scenarios can be understood through differing socioeconomic assumptions; *Issues and Options*, for instance, assumes higher rates of economic growth and economic structure more heavily weighted towards industry than the other studies, resulting in higher projections of energy use and carbon emissions.

The comparison of carbon emissions is very similar to that for energy demand, but differs slightly since each of the baseline scenarios resulted in different energy structures. In each scenario, carbon-intensive coal still dominated, but varied from 73% to 79% among the five scenarios considered above (Figure 6). Other studies discussed below (e.g., *Energy Development Strategy*) resulted in lower shares of coal, and thus less carbon-intensive futures, but even the most optimistic scenario assigns coal a two-thirds share of energy in 2020.

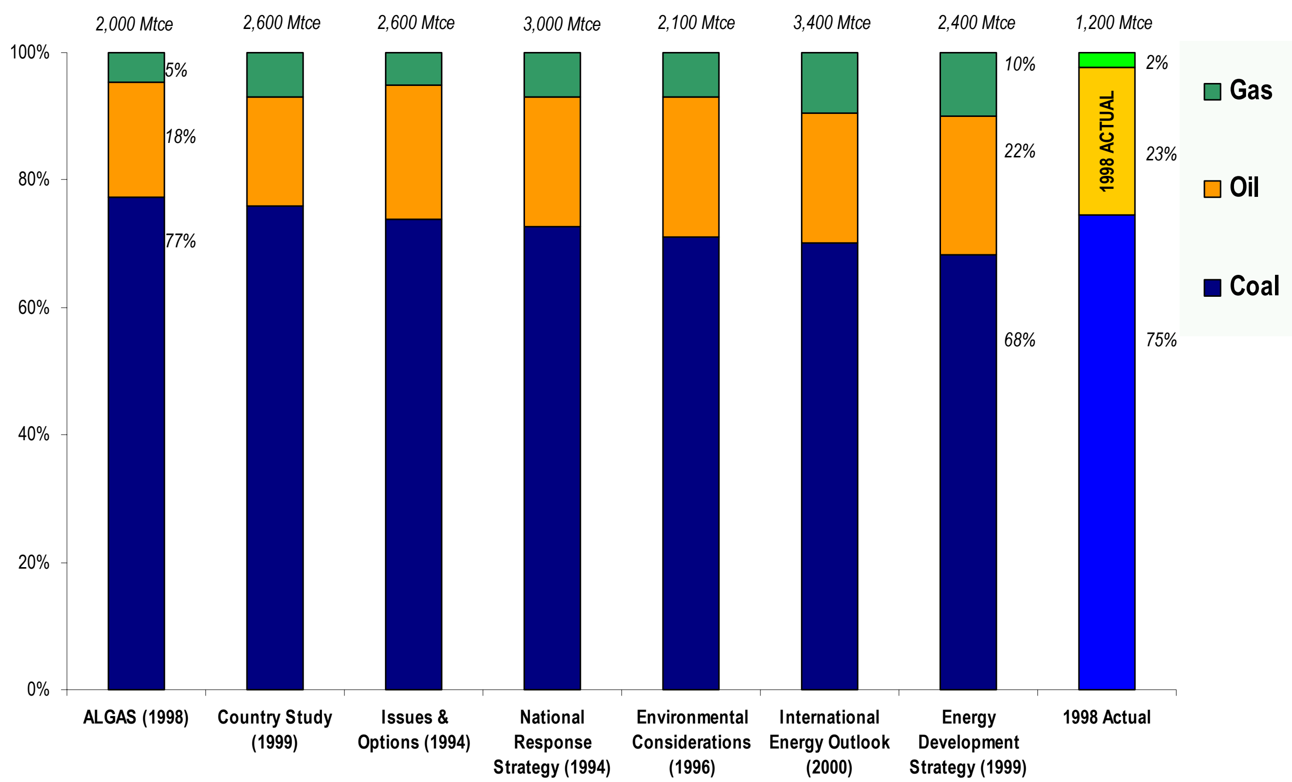


Figure 6. Comparison of Fossil Energy Supply Structures in 2020, Selected Baseline Scenarios

OTHER SCENARIOS STUDIES

The five studies above are the main studies produced in the last decade of energy-related greenhouse gas emissions from China, but they are by no means the only relevant studies. Below we briefly describe others that examined greenhouse gas emissions from important sectors (e.g., power generation) or energy supply and demand.

Energy Development Analysis for China in 2050

This study projected energy demand from 1990 to 2050 (Ministry of Energy, 1993). The "low" scenario in this study is similar to the baseline scenario in *Energy Development Strategy*, while the "high" scenario is similar to the Country Study baseline. In 2020, there is a slightly higher proportion of coal in the energy structure than in the other studies.

China's Energy—A Forecast to 2015

This report (LANL and PNNL, 1996) examines the effect of energy supply and demand in China on U.S. energy security. Business-as-usual and energy efficient demand scenarios are projected for the period between 1995 and 2015. It is predicted that actual energy demand will fall between these two scenarios. Notably, energy demand is projected to grow exponentially. Oil imports will reach up to 8.8 million barrels per day in 2015. Total energy consumption in 2015 could be 2,967 Mtce in the BAU scenario and 2,685 Mtce in the energy efficient. The BAU scenario is higher than most of the studies reviewed in this paper, and about the same as the baseline scenario in the *Issues and Options* study.

World Energy Outlook 1998

World Energy Outlook 1998 (IEA, 1998) analyzes major issues on the global energy stage, extending to the year 2020. Under the present scenario, the IEA forecasts that world energy demand will grow by 65% by 2020. The study projects that the world will use less coal (solid fuels), more natural gas, slightly more oil, less hydro, and more renewables.

World Energy Outlook 1998 forecasts that most of the growth in energy consumption will be in developing countries of Asia and Latin America. China is one of ten regions that are analyzed. Energy demand is analyzed through past and projected energy consumption for electrical services, mobility, stationary services, and fuels used in power generation. Energy supply is also analyzed, and important factors and uncertainties are discussed. By extrapolating from past GDP and energy growth, the economy (BAU) could be expected to grow about 5.5% per year and primary energy demand could be expected to grow at 3.6% per year in the period from 1995 to 2020.

Rather than strictly make energy projections, *World Outlook 1998* presents likely energy developments over the next two decades. It is the view of the IEA that problematic data and the dramatic changes in the Chinese economy and energy system generally make econometrically-derived projections inappropriate.

The Chinese energy sector has several unique and important features. The first is the uneven distribution of energy resources between regions. Second is the high level of energy consumption used for industrial applications (66%). Third, is the coming decline of biomass in total primary energy supply. A shift of biomass to higher quality fuels will increase efficiency, but it also implies a shift to coal, especially in rural areas. The study questions the accuracy of the energy elasticity figures for China. It hypothesizes that official statistics underestimate GDP level, while overestimating growth rate for the last two decades.

China's Electric Power Options: An Analysis of Economic and Environmental Costs

The aim of *China's Electric Power Options* (Battelle *et al*., 1998; related to *Electric Power Options* below) was to identify least-cost electric power and environmental options and to make appropriate policy recommendations. A collaboration between Beijing Energy Efficiency Center (BECon), Energy Research Institute of China (ERI), and the Advanced International Studies Unit of Battelle Memorial Institute, the study was supported by the W. Alton Jones Foundation. Seven regions in China were analyzed at five-year intervals. This report is concerned with greenhouse gas emissions and pollutants from the energy sector only.

This report had three primary goals. The first was to assess the state of power generation technologies in China. The second was to forecast regional electricity demand through 2020 and determine the least-cost combination of technologies to meet projected demand under five different policy scenarios. Third, an effort was made to recommend policies that could minimize economic as well as environmental costs.

A linear-optimization model, Energy-Flow Optimization Model/Environment (EFOM-ENV), was used to find least-cost means of meeting energy demand in the future. In order to assess different policy options, five scenarios were created: baseline, sulfur control, carbon dioxide control, natural gas policy, and advanced technology development. 1995 data were used to calibrate the 1990-2020 model.

This report included socioeconomic baselines. It is forecasted that China's demand for high-quality energy will continue to rise. The baseline scenario contains no environmental constraints. This is not labeled the 'business as usual' scenario because it is unlikely that China will continue on this path in the future. Projections are for every 5 years: 2000, 2005, 2010, 2015, 2020. Costs are included in the estimate.

Least-cost power generation was modeled. This included inter-regional energy flows. Rail transport, electricity transmission, shipping, and fuel import were included. Base years were 1990 and 1995 and fuel costs of coal, oil, and natural gas were considered.

One important purpose of this analysis was to determine whether China could meet both its economic and environmental goals by applying new technologies. The results of the model show that policies to promote scrubbers and precipitators on coal-fired power plants, along with natural gas, renewable energy, and advanced power generation technologies are appropriate technologies

Reform of the electric power industry and environmental protection are changing the dynamics and the future of the electric power industry. Recommendations presented in the report include: improving the energy supply mix, improving efficiency in the electric power sector, improving fuel quality, locating coal-fired power plants wisely, using SO_2 reduction technologies, and developing advanced energy technologies.

China's Energy and Economy in the 21st Century

This study (CASS, 1999) contains projections for China's primary energy demand and energy structure from 2000 to 2050. It is forecast that energy intensity will drop sharply in the next fifty years, that coal use will decline to 52% of total fuel use by 2050, and that energy consumption per capita in China in 2050 will reach average world consumption of the 1990s. CO_2 emissions from coal will almost double between 2000 and 2050, while CO_2 emissions from natural gas and oil will more than double. Table 14 shows the detailed projection.

Table 14 CO2 Emissions from Fossil Fuel Burning

	2000	2010	2020	2030	2050
CO_2 Emissions from Coal (MtC)	701	890	1050	1160	1350
CO_2 Emission from Oil and Natural Gas (MtC)	140	200	280	330	370

A reduction of coal use to 50% and an increase in other technologies are suggested as "solutions" for the 21st century. Specific actions include the acceleration of nuclear energy, renewables, and biomass utilization; an increase in energy efficiency; and the development of solar heating, coal-based syn-fuel, geothermal power, and clean coal technologies.

Study on Long Term Energy Development Strategies in China

Long Term Energy Development Strategies of China (Zhou and Zhou, 1999) compared energy demand forecasts for China to 2050 that were developed by four different organizations in China . Their results are summarized in Table 15. A coal-based and an oil- and gas-based alternative energy future was forecast for the decade between 2020 and 2030, and for the year 2050. As expected, efficiencies for oil- and gas-based technologies were higher than for coal-based technologies.

Table 15 Sectoral Energy Demand Forecasting: A Comparison of Per Capita Energy Demand

Forecasting Organization	Per Capita Energy Demand (tce)			
	2000	2010	2020	2050
Energy Research Institute	1.15	1.46	1.70	--
Tsinghua University	1.07-1.32	--	1.52-1.92	2.12-2.82
Former Ministry of Energy	1.11-1.18	--	1.64-1.85	2.23-2.82
China Engineering Academy	1.27-1.31	1.60-1.69	1.95-2.11	2.33-2.70

International Energy Outlook

The *International Energy Outlook* (EIA, 2000) covers energy consumption of countries throughout the world, and is published by the Energy Information Administration of the U.S. Department of Energy. Projections for China extend to the year 2020. As a developing economy of Asia, China is expected to experience fast-paced economic growth. A reference case, as well as high economic growth and low economic growth cases are included in the forecasts.

International Energy Outlook projected the greatest total energy consumption of all the studies. At 3,386 Mtce, it was almost 400 Mtce greater than the next highest projection. In terms of fuel structure, International Energy Outlook predicted one of the smallest proportions of coal and largest proportions of natural gas. It showed a similar fraction as Energy Development Strategy. The study did not incorporate forecasts for CO_2 emissions. In order to estimate emissions based on fuel use, carbon coefficients from the Country Study were used. As expected, the resulting carbon emissions were higher than projections from other studies. In 2020, the emissions were 10% higher than emissions for *Issues and Options*, the next highest projection. The baseline in this study provides the upper bound for scenarios reviewed here.

Developing Countries and Global Climate Change: Electric Power Options in China

Electric Power Options (Zhou, *et al*., 2000) is one of a series detailed case studies examining the electric power sector in developing countries (Korea, India, Brazil, and Argentina are the other four). Researchers from BECon, ERI, and the Advanced International Studies Unit of Battelle authored the report and the work was funded by the Pew Center on Global Climate Change. The main objective was to identify options for fulfilling future energy demand, while limiting environmental damage. A baseline case projected that by 2015, coal would provide 85% of power in China. A less carbon-intensive future was forecasted in five additional scenarios which incorporated specific policy measures: sulfur dioxide control, carbon dioxide control, natural gas, clean coal, and energy efficiency. The energy efficiency scenario provided the lowest level of carbon emissions in the year 2015. The sulfur dioxide control scenario provided the least benefit for carbon emission reduction, though it was still less carbon-intensive than the baseline case. Unlike the other studies, this one divided China into regions, allowing analysis of important geographic variation.

Generation, capacity, cost, carbon dioxide emissions, and sulfur dioxide emissions were projected for each case, using a linear programming model (optimization program). The baseline power demand projection was based on forecasts from ERI and others, which predicted that electricity demand would grow from 1,002 TWh in 1995 to 2,740 TWh by 2015. In the carbon dioxide control scenario, both a carbon emissions cap and carbon taxes were examined. It was determined that carbon taxes would have no impact unless the tax was higher than $25 per ton of carbon, and the tax would have only limited effect under $75 per ton. At a $125 per ton tax, coal-fired power output would be reduced to 3% of total generation. When a carbon cap was imposed, washed coal, hydropower, natural gas, and nuclear power appeared to be cost-effective options for standard coal. However, nuclear power and hydropower have high capital costs and long construction lead-times.

Why Is There a Need for the Present Scenarios Project?

As this paper has shown, a number of scenario studies have already been conducted to evaluate the potential for improving energy efficiency in China and reducing energy-related carbon dioxide emissions. These studies has had a number of important benefits. Before these projects were done, researchers and policy makers in China had a limited understanding of the link between energy and greenhouse gas emissions, and very little experience with the tools and date needed to conduct policy analysis of energy efficiency and other mitigation measures. The process of putting these studies together trained a large group of researchers in techniques of data-gathering and analysis, and gave them an understanding of the place of such analysis in policy making. In preparing these studies, the energy research community forged new links with experts in other sectors, giving them new insights and access to new information that they had not had before. Th results of the scenarios studies were circulated in policy-making circles, and increased awareness of the potential for effectively reducing future energy demand and energy-related pollution.

Why is there then a need for another study? At the very least, such studies need to be updated to account of changed circumstances. Total energy use—and therefore total greenhouse gas emissions—have fallen significantly in China since 1996. None of the studies discussed here anticipated such a trend, and future studies will need to reflect the phenomenon. Even the *China Country Study*, published in 1999, was not based on up-to-date data (although, to be fair, most of the analytic work was begun in the mid-1990s). It is widely expected that China will resume growth in total energy demand, however, and thus the results of previous studies still have relevance, as the basic forces of change that are considered in those studies are still at work. Since unanticipated factors, e.g., the Asian financial crisis, rapid industrial restructuring, and a glut in domestic coal markets, contributed to the decline in energy use, pointing up the usefulness of producing alternate scenarios that include such "surprises".

Aside from the ongoing need to produce updated scenarios that take account of new developments that were not anticipated in previous studies, there are a number of weaknesses in previous studies that this project seeks to address.

- Researchers treated the studies in some ways as academic studies, with more attention paid to getting the analytic work done correctly than to making sure that views of stakeholders were taken into account from the very beginning. While the studies were extremely effective as learning exercises, they were less influential on policy than they might have been.
- The studies tended to overestimate the potential for energy-efficiency improvements. The potential to reduce demand for fossil fuels through energy efficiency and renewable energy was often calculated through simple comparisons with advanced technologies, with insufficient regard to cost-effectiveness and barriers to deployment.
- Some studies adopted a top-down approach, which is inappropriate for detailed evaluation of specific policies, since a relatively high level of technical detail in energy end-use sectors is needed to analyze sector-specific policies. Some studies provided insufficient detail on the content of the policy scenarios.
- Cost-benefit analysis in the studies was often based on inadequate information, generated during a period of transition from a planned to a market-based economy. While some conclusions in the studies remain valid, most needs to be updated to reflect changed circumstances. This is crucial, as cost-benefit analysis provides key information to policy makers.

- Most studies were one-off projects, with no plans for continued use of products. In order to be most effective, scenarios should be used as tools to answer questions and highlight important findings in a continuing dialogue with policy makers. According to this view, a written study is, in a sense, a byproduct of an ongoing process.

Of course, no single approach can overcome all of the deficiencies of previous studies, or would be appropriate for all tasks. The result of the Scenarios Project, however, is intended to be a tool that can fill in the gaps left by previous studies, a set of scenarios that are applied to answer questions about the specific choices that China's energy planners are currently facing, and a core group of energy policy analysts who can answer policy-relevant questions. Some of the advantages of the Scenarios Project are explained below.

HIGH LEVEL OF TECHNICAL DETAIL

Unlike most previous studies, the Scenarios Project takes an approach that emphasizes detailed demand-side analysis, often called a "bottom-up" approach. Most of the energy-using equipment that will be in place at the endpoint of this study (2020) will be built between now and then. A detailed understanding of the technologies in place now and those that will be adopted in the future is therefore required in order to analyze the energy-efficiency and renewable-energy policies and programs that might be put in place—since they are, essentially, designed to influence technology choices.

Some previous studies have examined sectors in some detail. The *Issues and Options* study, for instance, projected steel output, and compared energy use and carbon emissions under a BAU scenario, and a scenario under which four specific technical measures, which had been analyzed as being cost-effective, were adopted more quickly in the sector than under the BAU scenario. The Scenarios Project will build on these past efforts to understand how specific sets of technology choices may affect energy use by adding technical detail, as well as producing an updateable model that can be used to compare a variety of scenarios on the basis of energy demand, carbon emissions, and cost.

CAPACITY FOR ONGOING SCENARIO-BASED POLICY ANALYSIS

The development of an updateable model with a great deal of technical detail in end-use sectors is key to the creation of an institutional capacity to apply scenario-based analysis to the energy policy choices that China faces. As conditions in China continue to change, the baseline conditions assumed in scenarios will change, as will the policy options available. A well-documented, internally consistent model could be modified as needed, and used to quickly and easily make incremental adjustments to previously constructed scenarios, and to create new ones. Rather than producing a one-shot report, then, as most previous studies have, this project aims to create a tool—and a core group of analysts to run it—that can continue to provide up-to-date results well into the future. The project aims to create a tool, and a core of technically qualified individuals to run it, that can be used to provide scenario-based analysis to support policy-makers' needs for evaluation of the potential impacts of individual policies and sets of policies.

STRONG LINK TO NATIONAL PLANNING AND POLICY MAKING

The team responsible for running the model and creating scenarios will not be working in isolation, but will be synthesizing information from many sources in industry, academia and government (including sectoral and coordinating bodies at the national and provincial levels), and providing analytic results and recommendations directly to China's national energy planners in the State Development Planning Commission (SDPC). The process of seeking input from a broad range of sources is helping introduce concepts of scenario-based policy analysis, and is developing a broad-based community that has a stake in project outcomes. The scenarios team, centered at BECon, is already closely involved in providing SDPC with policy analysis in support of the energy efficiency provisions of the Tenth Five-Year Plan, among other activities. The modeling and scenario analysis would be used as an additional tool to provide quantitative assessments of policy measures actually being considered by SDPC. One possible application of the model may eventually be to provide companion analysis, e.g., recommendations for energy-conservation targets, for the Tenth Five-Year Plan and its annual updates.

KEY ISSUES FOR THE SCENARIOS PROJECT

Previous studies of energy and carbon scenarios have highlighted some of the key issues that will be important to consider in the Scenarios Project. In concluding this paper, we list a few of these for consideration in designing scenarios for this project; many other issues are likely to be important to various groups. A broad consensus should be sought on what the important drivers to include in the scenarios are. This will aid in addressing the issues most important to the stakeholders in this process, and help ensure that the results of this study are relevant to the needs and concerns of a wide cross-section of the policy-making community.

Socioeconomic Drivers

Many of the differences between previous scenarios were due to differences in very basic parameters, such as rate of GDP growth and population. The relationship between GDP and demands for goods and services will be a large determinant of future energy use.

Economic Structure

China has recently experienced a large fall in energy use, which is probably closely related to rapid changes in structure of the industrial economy. This illustrates the tremendous impact of shifts in economic structure—changes that may have little to do with energy policy per se, and more to do with broad domestic economic trends, international economic relations (e.g., accession to the World Trade Organization) and socioeconomic policy. It is essential that scenarios take careful account of possible structural changes.

Urbanization

City dwellers tend to be wealthier and use more energy than people in rural areas. As China continues to urbanize, per capita energy demand will rise and energy demand structure will change. The course of urbanization will have a strong influence on the country's energy future.

Transport Issues

In most countries, there is a positive relationship between per capita GDP and the number of passenger vehicles per capita. There is also clearly a relationship to rate of urbanization. It is reasonable to anticipate that China will follow a similar growth pattern, bringing increased oil demand and pressure on the urban environment. Expansion of national and international markets will also result in increased interregional passenger and freight traffic. These trends, and efforts to change patterns of transport demand as well as the efficiency and fuel structure of vehicles and other transport equipment, will determine a significant portion China's energy future.

International Energy Markets

As oil demand rises, and China contemplates large natural gas projects, the country will be drawn more deeply into participation in international energy markets. A thorough understanding of the factors likely to affect future energy market dynamics is essential for producing well-informed scenarios.

Energy Security

The recent increase in the international price of oil has raised questions about how increasing dependence on imported oil will affect China. With rapidly increasing transport demand, energy security issues will become increasingly prominent.

Power Generation Issues

Utility sector restructuring is one of the key variables that will affect China's energy future. It will affect how efficiently power is generated and from what sources, what electricity costs, among other things.

Energy Efficiency and Renewable Energy Technology

Finally, the progress of development of energy efficiency and renewable energy technologies will have a profound impact on the course of future energy demand and the carbon intensity of energy supply. Strong technical and economic analysis of these factors is needed for meaningful representation of technological change in scenarios.

References

Asian Development Bank, Global Environment Facility, United Nations Development Programme. 1998. *Asia Least-cost Greenhouse Gas Abatement Strategy: People's Republic of China.* Manila: Asian Development Bank. October.

Battelle Memorial Institute, Beijing Energy Efficiency Center, China Energy Research Institute. 1998. *China's Electric Power Options: An Analysis of Economic and Environmental Costs*. Washington, DC: Pacific Northwest National Laboratory. June.

Chinese Academy of Social Sciences. 1999. *China's Energy and Economy in the 21st Century (21 Shiji De Zhongguo Nengyuan Yu Jingji)*.

East-West Center, Argonne National Laboratory, and Tsinghua University. 1994. *National Response Strategy to Global Climate Change: People's Republic of China*. Final Report of the Technical Assistance Project (TA 1690-PRC). Manila, Philippines: Asian Development Bank. September.

Energy Information Administration. 2000. *International Energy Outlook 2000*. Report No. DOE/EIA-0484. Washington, DC: Energy Information Administration, US Department of Energy.

Los Alamos National Laboratory and Pacific Northwest National Laboratory. 1996. *China's Energy—A Forecast to 2015*. Report No. LA-UR-96-2972. Los Alamos: Los Alamos National Laboratory.

Ministry of Energy (former). 1993. *Energy Development Analysis for China in 2050 (2050 Nian Zhongguo Nengyuan Fazhan Zhanlue Yanjiu)*. (In Chinese)

National Environmental Protection Agency of China, State Planning Commission of China, United Nations Development Programme, and the World Bank. 1994. *China: Issues and Options in Greenhouse Gas Emissions Control.* Washington, DC: World Bank. December.

Organization for Economic Cooperation and Development (OECD). 1991. *Estimation of Greenhouse Gas Emissions and Sinks*. Final Report from the OECD Experts Meeting. Paris: OECD.

Research Team of China Climate Change Study. 1999. *China Climate Change Country Study*. Beijing: Tsinghua University Press.

State Statistical Bureau. 1991. *Zhongguo Nengyuan Tongji Nianjian (China Energy Statistical Yearbook) 1991*. Beijing: China Statistical Publishing House.

United Nations Environment Programme, and National Environmental Protection Agency of China. 1996. *Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China*. Beijing: China Environmental Science Press. November.

World Bank and Joint Study Group (National Environmental Protection Agency of China, State Planning Commission of China, United Nations Development Programme). 1994. *China: Issues and Options in Greenhouse Gas Emissions Control.* Washington, DC: World Bank. December.

ZHOU Dadi, GUO Yuan, SHI Yingyi, Chandler, William, and Logan, Jeffrey. 2000. *Developing Countries and Global Climate Change: Electric Power Options in China*. Arlington: Pew Center on Global Climate Change. May.

ZHOU Fengqi and ZHOU Dadi, eds. 1999. *Study on Long Term Energy Development Strategies of China (Zhongguo Zhongchangqi Nengyuan Zhanlue).* Beijing: China Planning Publishing House (*Zhongguo Jihua Chubanshe*). (In Chinese)

Appendixes

1. **Acronyms and Abbreviations**
2. **Normalization of Carbon Emissions Scenarios**
3. **Additional Energy Demand Scenarios for China Prepared in the 1980s and Early 1990s**

APPENDIX 1. ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
AISU	Advanced International Studies Unit of Pacific Northwest National Laboratory
ANL	Argonne National Laboratory
BECon	Beijing Energy Efficiency Center
BMI*	Battelle Memorial Institute
CASS	The Chinese Academy of Social Sciences
CMRI	China Macroeconomic Research Institute
EIA	Energy Information Administration
ERI	Energy Research Institute of the State Development Planning Commission of China
EWC	East-West Center
GEF	Global Environment Facility
IEA	International Energy Agency
INET	Institute of Nuclear Technology, Tsinghua University
LANL	Los Alamos National Laboratory
NEPA	National Environmental Protection Agency of China
OEI	US DOE's Office of Energy Intelligence
Pew	Pew Center for Global Climate Change
PNNL*	Pacific Northwest National Laboratory
SPC	State Planning Commission of China
SSTC	State Science & Technology Commission of China
STSD	Department of Science and Technology for Social Development, State Science and Technology Commission of China
TU	Tsinghua University
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
US DOE	United States Department of Energy
WB	The World Bank

*Pacific Northwest National Laboratory is also known as Battelle Memorial Institute

Appendix 2. Normalization of Carbon Emissions Scenarios

Direct comparisons of the results of the scenarios reviewed in this paper are difficult because all assumed different carbon emission coefficients. This results in differences such as significant variation among the studies in estimates of carbon dioxide emissions in the base year (1990). In order to make consistent comparisons, the emissions estimates from the various studies were normalized using a single set of carbon emission coefficients, i.e., those from the *Country Study*. In addition, we calculated carbon dioxide emissions based on two studies that presented energy projections only, and based on actual energy use for 1990 to 1999, as published in the *China Statistical Yearbook*. Figure 2 shows baseline scenarios of energy consumption from seven studies, compared to actual energy use, and Figure 3 shows estimates of carbon dioxide emissions based on those energy scenarios.

Normalization Method

Historical and projected energy use by fuel in each of the seven studies were multiplied by the carbon emissions per unit of each fuel, as defined in the *Country Study* (Table 16). Numbers from the *Country Study* were chosen in part because this was the only study that estimated the future increase in the carbon emission coefficient for coal. Expected improvements in energy efficiency (through improved end-use technology and equipment operation) and coal quality were among the factors taken into account in projecting carbon emissions per unit of coal. Another reason for using the *Country Study*'s carbon emission coefficients is that they were estimated to reflect actual conditions in China, unlike the standard or placeholder factors used in some studies. The Inter-governmental Panel on Climate Change (IPCC) recommended a default value for average oxidized fraction of coal combustion at 98%, and some studies used higher values, e.g., the *Issues and Options* study used a value of 99%. The country study, on the other hand, considered specifics of coal quality (e.g., 27% average ash content, use of unwashed coal) and combustion equipment (large proportion of small- and medium-sized equipment) when developing these carbon emission coefficients. The study calculated that an average oxidation fraction of 89.6% was representative of actual conditions in China in 1990, and that this value has risen and will continue to rise.

Table 16. *China Country Study* Carbon Emission Coefficients

	Carbon Emission coefficients					
	(kg-c/GJ)			(kg-c/kgce)		
Year	**Solid Fuels**	**Liquid Fuels**	**Gaseous Fuels**	**Solid Fuels**	**Liquid Fuels**	**Gaseous Fuels**
1990	22.3	16.1	14.0	0.653	0.473	0.409
2000	22.8	“	“	0.668	“	“
2010	23.5	“	“	0.689	“	“
2030	24.3	“	“	0.711	“	“

Source: Research Team of China Climate Change Study. 1999. *China Climate Change Country Study.* Beijing: Tsinghua University Press. p 280.

The *Country Study* estimated average emission coefficients for solid fuels for 1990, 2000, 2010, and 2030. For normalization, consumption of each energy product as estimated in each study was multiplied by the carbon emission coefficient for the corresponding year. For studies that estimated energy use for years other than those considered in the *Country Study*, the *Country Study* emissions factor from the year which was closest but not above the designated year was used. For instance, 2010 *Country Study* emission coefficients were used to calculate emissions in 2020 for *Issues and Options* and other studies that estimated energy use for 2020.

The coefficients listed in Table 16 are weighted averages, published in the *Country Study*, for about two dozen different fuels. The emission coefficient for liquid fuels, for instance, is an average for 11 different types of petroleum product. Since each study broke out fuels differently and had a different set of emission coefficients, it was necessary to use averages for three broad categories of fuel. This necessarily introduces some inaccuracy, as each scenario projects a different mix of fossil fuel use. To check the accuracy of this method, carbon emissions were calculated using energy use figures from the *Country Study* in the same manner as emissions were calculated for the other studies. Variation in the calculated numbers compared to the numbers presented in the *Country Study* ranged from 0.7% to 3%. This is a relatively small variation compared to the results of applying the coefficients to two of the other studies (*Environmental Considerations* and *Issues and Options*), so we consider this method to be appropriate for use in normalizing emissions for the purpose of making approximate comparisons.

Results and Interpretation

As expected, the normalized carbon dioxide emissions graph basically mirrors the energy graph, as there is a direct correlation between energy use and carbon emissions. Differences between the two charts reflect differing projections of changes in fuel structure. The scenarios all begin at around 600 MtC in 1990 and project a rise in carbon emissions. *National Response Strategy* and the *China Country Study* project slower growth of carbon emissions, while *Energy Development Strategy* and *Issues and Options* (as well as *International Energy Outlook*, if emissions are calculated from its energy use scenario), projected steeper increase in carbon emissions in the future.[6] *International Energy Outlook* shows the steepest incline, with an expected CO_2 emissions in 2020 more than 60% higher than those projected in the baseline scenarios in *Environmental Considerations* or *National Response Strategy*. This is due in part to the larger share of coal use that is predicted in *International Energy Outlook.*

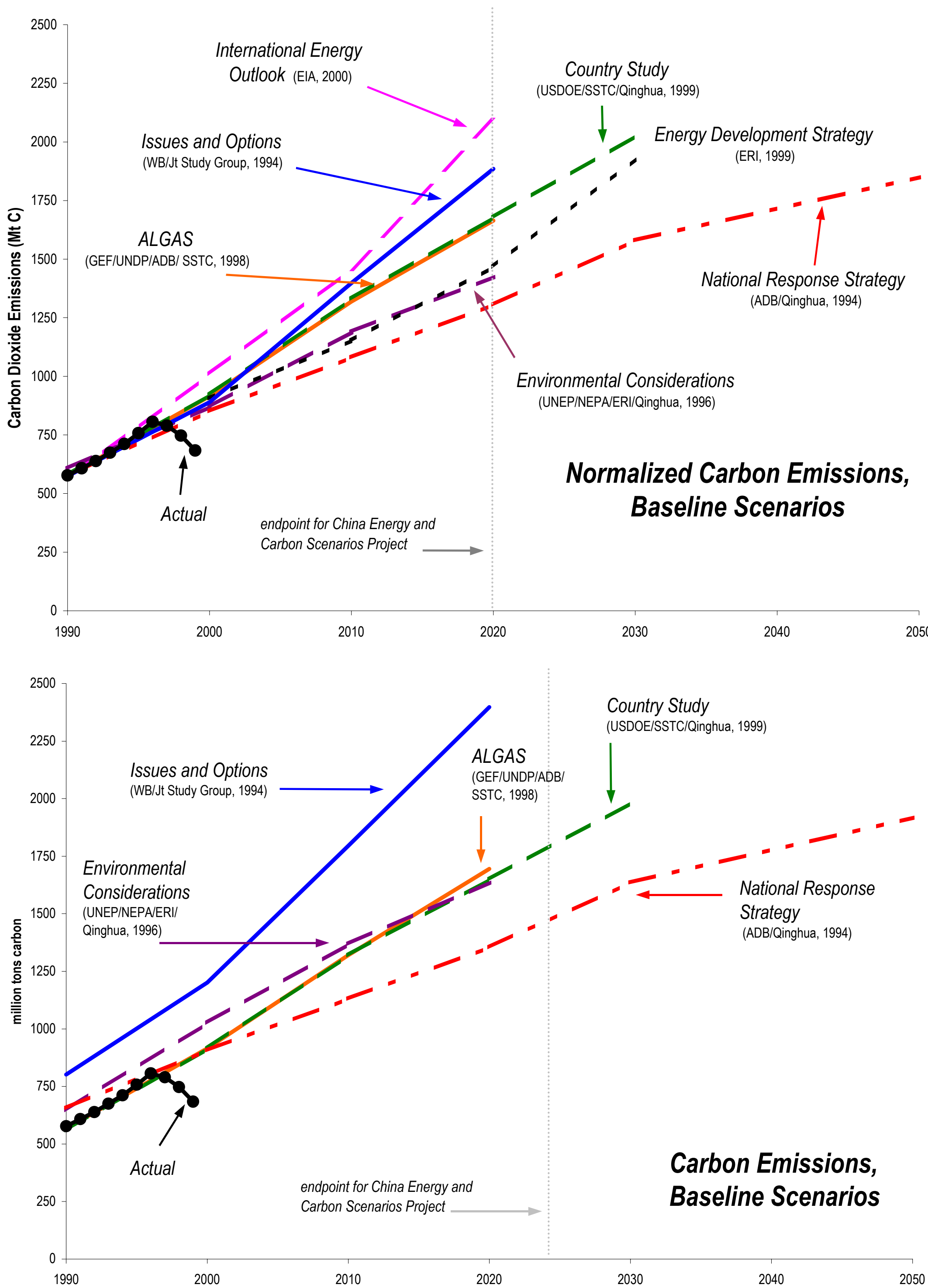
Table 17 Comparison of Non-normalized and Normalized Baseline Scenarios of Carbon Dioxide Emissions (Mtce)

	Non-normalized CO_2 Emissions in 2020	Normalized CO_2 Emissions in 2020
ALGAS	1,695	1,664
China Country Study	1,650*	1,678*
Environmental Considerations	1,636	1,313
Issues & Options	2,398	1,886
National Response Strategy	1,354	1,336
International Energy Outlook	-	2,093

* Interpolated between projections for 2010 and for 2030.

[6] *Energy Development Strategy* and *International Energy Outlook* only provided energy data and did not project carbon emissions. LBNL prepared the emissions estimates associated here with those studies.

Figure 7 Normalized Carbon Emissions Scenarios Versus Non-Normalized Carbon Emissions Scenarios



Normalization reduced the apparent difference between the emissions scenarios (Table 17). In the non-normalized baseline forecasts, illustrated in Figure 7, baseline carbon dioxide projections in 2020 ranged from 1354 Mtce (*National Response Strategy*) to 2398 Mtce (*Issues and Options*). In the normalized forecasts, *Issues and Options* still projected the highest carbon dioxide emissions, but the range between studies was far smaller. Normalized forecasts ranged by only 573 Mtce, as opposed to more than 1,000 Mtce for the non-normalized studies.

Figure 6 compares the baseline energy structures of seven studies in 2020. The projected share of coal use varies from 68% to 79%.[7] *International Energy Outlook* and *Issues and Options* predict the highest levels of coal use and of overall energy use, and consequently, the highest levels of carbon dioxide emissions. However, these two studies do not project the highest *proportion* of coal use in the fuel mix. *Environmental Considerations*, which actually projected the lowest overall energy use, projected the greatest proportion of coal use. This study was drastically affected by normalization of carbon emission coefficient. The non-normalized carbon dioxide projection fell in the middle range of the studies, and in 2020 converged at virtually the same level as *ALGAS* and the *Country Study*. However, in the normalized projection, the *Environmental Considerations* estimate of emissions in 2020 fell by one fifth, making it the lowest baseline projection.

Figure 2 and Figure 3 also compare the various scenarios of energy use and carbon emissions to actual energy use and emissions from 1990 to 1999. In 1996, when China's energy use was at its historic peak, actual energy consumption was greater than that projected in all scenarios, except the *International Energy Outlook*. However, actual carbon dioxide emissions in the three years since have dipped below projected levels because of the dramatic downward trend in actual energy use.

[7] For comparison, coal's share of primary energy use in 1999 was 67%, down from a peak of over 76% from 1987 to 1991 (National Bureau of Statistics, 1999 and 2000).

APPENDIX 3. ADDITIONAL ENERGY DEMAND SCENARIOS FOR CHINA PREPARED IN THE 1980S AND EARLY 1990S

Researchers in China have long used a variety of approaches and models to produce scenarios of future energy use. Table 18 below (based on Yang and Levine, 1993) summarizes the approach taken by and results from 15 studies conducted between 1984 and 1993. Like the more recent studies reviewed in this paper, even the lowest scenarios produced estimates for energy use in 2000 that are far higher than expected actual consumption. Still, this table demonstrates that the research community in China has a large body of experience to draw on in conducting the scenario-based analysis of energy use and resulting pollutant emissions required in the Scenarios Project.

Table 18. China's Energy Demand Forecasting Approaches

Approach	Author, Publication Date	Model	Base Year	Forecasting Results		Evaluation	
				Year	Energy Demand (Mtce)	Advantages	Disadvantages
Conventional Indices	WANG Qingyi, August 1988	Elasticity Index	1980	2000	Scenario 1: 1200-1300 Scenario 2: 1600-1700 Scenario 3: 2400	• simple • less resource-intensive	• somewhat arbitrary • less information for other factor impacts • no consideration for price reform and political effects
	RONG Tao, July 1992	Sectoral Elasticity Indices	1990	2000	Low: 1365 High: 1404	• uses sectoral elasticity	• same disadvantages as the model above
Econometrics	CHU Ming and WANG Congyin, April 1992	ENERPLAN	1990	1995	Total: 1293 Coal: 942 Oil: 235 Natural Gas: 44 Hydropower: 75 Electricity (TWh): 874	• easy to incorporate economic factors into the model • good for short-term energy forecasting • analyzes historical data	• no price accounting • no effects of political and social factors in the model • difficult to use for long-term energy forecasting
Sectoral Analysis	The World Bank, May 1985	Integrated Sectoral Analysis	1980	2000	Low Scenario Primary Energy: 1428 End-Use Energy: 1303 Electricity: 382 High Scenario Primary Energy: 1900 End-Use Energy: 1756 Electricity: 558	• very detailed analysis of individual sectors • uses historical data for future trends • model incorporates policy impacts • scenarios can be designed	• inappropriate assumptions for some key factors • little evaluation for energy conservation • no accounting for features of economic transition

APPROACH	Author, Publication Date	Model	Base Year	Forecasting Results		Evaluation	
				Year	Energy Demand (Mtce)	Advantages	Disadvantages
Sectoral Analysis (continued)	QU Shiyuan, June 1990	MEDEE-S	1985	2000 2015	Total: 1559 Coal: 1107 Oil: 374 Natural Gas: 43 Hydropower: 32 Nuclear Power: 3 Total: 2500 Coal: 1565 Oil: 673 Natural Gas: 176 Hydropower: 66 Nuclear Power: 20	• commercial software • less data requirements and lower quality data requirements • energy intensive products are classified • detailed sectoral analysis	• rigid software design is less flexible for operators • environmental and macroeconomics factors are omitted • changes in economic structure and product mix are not fully considered
	WU Zongxin *et al*., September 1990	EAA	1985	2000 2020 2050	Government Planning Total: 1440 Oil: 286 Natural Gas: 40 Hydropower: 100 Renewable: 0 Nuclear Power: 14 Coal: 1000 Total: 2500 Oil: 358 Natural Gas: 133 Hydropower: 210 Renewable: 10 Nuclear Power: 91 Coal: 1700 Total: 4000 Oil: 171 Natural Gas: 213 Hydropower: 310 Renewable: 100 Nuclear Power: 750-250 Coal: 2445-2956	• very detailed analysis for various sectors • reliable comparison with other countries • considers changes in economic structure and sectoral patterns • appropriate scenario designs	• economic transition features are not incorporated into the approach • political uncertainty and the economic cycle are omitted • international energy market and conservation are not considered

APPROACH	Author, Publication Date	Model	Base Year	Forecasting Results		Evaluation	
				Year	Energy Demand (Mtce)	Advantages	Disadvantages
Sectoral Analysis (continued)	Institute of Nuclear Technology, Tsinghua University, February 1992	Demand Side of ETO	1990	2000 2020	**Primary Energy** Scenario 1: 1480 Scenario 2: 1393 Scenario 3: 1379 (baseline) Scenario 4: 1329 Scenario 1: 2679 Scenario 2: 2498 Scenario 3: 2429 (baseline) Scenario 4: 2374	• connects to supply and gas emissions modeling as inputs • possesses advantages similar to Wu *et al*., 1990	• too many scenarios • has shortcomings similar to Wu *et al*., 1990
	XI Xiaolin, Ph.D. Dissertation, March 1993	Scenario and Uncertainty Analysis	1985	2000 2020 2050	Primary Energy: 1812 Primary Energy: 3018 Primary Energy: 6226	• conducts uncertainty analysis • refers to experiences in other countries • includes biomass energy in the model	• does not fully address the role of energy conservation • contains some arguable assumptions • effects of structure change are not included
Regional and Sectoral Analysis	Energy Research Institute, January 1993	Multiple Regions, Sectors, and Energy Types	1988	1995 2000 2010	**Primary Energy Use** Low Scenario: 1225 High Scenario: 1330 Low Scenario: 1468 High Scenario: 1710 Low Scenario: 2075 High Scenario: 2680	• accounts for regional differences in economic development and energy patterns • employs sector analysis in each region • very detailed analysis for energy demand for regions, sectors, and energy types • establishes a data bank	• connections between regions are not considered • some inappropriate assumptions in economic and sectoral development. • too much information requirements • resource-consuming
Input/Output	LU Yingzhong, June 1990	Dynamic I/O	1980	2000 2020 2050	Primary Energy: 1651 Electricity (TWh): 1200 Primary Energy: 3530 Electricity: 3500 Primary Energy: 4706 Electricity: 5180	• clearly illustrates sectoral relationships • has second order effects • distinguishes important factors in sequence	• high cost in data collection and computer time • difficult to account for coefficients over time • excludes non-linear and political factors

APPROACH	Author, Publication Date	Model	Base Year	Forecasting Results		Evaluation	
				Year	Energy Demand (Mtce)	Advantages	Disadvantages
Input/Output (continued)	LEI Suxuan, June 1990	Mixture Models	1990	2000	Lower Bound Total: 1560 Oil: 250 Natural Gas: 25 Hydropower: 89 Nuclear Power: 18 Coal: 1178 High Bound Total: 1700	• combines I/O and sector analysis for economic structure changes	• resource-consuming • employs I/O and sectoral analysis for the lower bound and the elasticity approach for the upper bound • inconsistency between the two methods employed
Optimization	ZHANG Aling, April 1993	Optimization Linear Programming	1990	2000	Scenario 3 at High Growth Rate: 1606-1540 Scenario 3 at Low Growth Rate: 1385-1330	• incorporates sectoral analysis and scenarios into the model • distinguishes effects of various factors	• distorted energy costs in objective function • no concern for price and investment impacts • too many options considered
Expert Judgment	ZHU Liangdong & WANG Baohua, September 1990	Adjusted Elasticity	1988	2020	Scenario 1 Primary Energy: 227 Electricity (TWh): 2500 Scenario 2 Primary Energy: 255 Electricity (TWh): 3000 Scenario 1 Primary Energy: 320 Electricity (TWh): 4400	• simple • incorporates energy expert experiment and insight for the future development	• less burdensome data requirements • involves subjective predictions

APPROACH	Author, Publication Date	Model	Base Year	Forecasting Results		Evaluation	
				Year	Energy Demand (Mtce)	Advantages	Disadvantages
	LIN Fatang, September 1990	Comparable Scenario	1988	2000 2050	Primary Energy: 1440 Oil: 286 Natural Gas: 40 Hydropower: 100 Nuclear Energy: 14 Coal: 1000 Primary Energy: 3096 Oil: 171 Natural Gas: 213 Hydropower: 310 Renewable: 100 Nuclear Energy: 500 Coal: 1802	• refers to development experiences in other countries • simple	• questionable comparison of data and information among countries • a lack of options in special development trends for China • ignores non-monetary value indices
Rural Projection	ERI & IAERD, October 1990	Multiple Period Programming	1987	2000	**Scenario 1** Total: 673 Residential: 328 Agriculture: 34 Rural Enterprises: 310 **Scenario 2** Total: 633 Residential: 327 Agriculture: 31 Rural Enterprises: 275	• incorporates changes in policy, and economic and social factors into each period • considers strengthened energy conservation, especially in residential sector • considering special condition in rural areas	• assumes same residential consumption level in both scenarios • much lower growth rates assumed for residential energy requirements and rural enterprise development

Appendix 3 References

CHU Ming and WANG Congying. 1992. "Analysis for Energy Demand/Supply Forecasting in the Eight Five Year Plan -Application of ENERPLAN." working paper. Institute of Energy Research. April.

LEI Suxuan et al. 1990. "Exploration of China Energy in the Year 2000." working paper. Chinese Society of Energy Research. June.

LIN Fatang. 1990. "Initial Analysis and Scenarios for Energy Development in 2050." working paper. *China's Energy Forecasting in 2050*. September.

LU Yingzhong. 1990. "Some Problems in Energy Demand Forecasting and Strategy in China." working paper. Chinese Society of Energy Research. June.

QU Shiyuan. 1990. "Energy Demand Forecasting in the Medium and Long Terms." working paper. Chinese Society of Energy Research. June.

RONG Tao. 1992. "Energy Demand Forecasting in the Year 2000." working paper. Institute of Energy Research, State Planning Commission.

WANG Qingyi, ed. 1988. *Energy in China*. Beijing: Metallurgical Publishing Inc. August.

World Bank. 1985. *China, the Energy Sector.* Washington, DC: World Bank.

WU Zongxin et al. 1992. *Technological Adoption and Economic Evaluation for Reducing CO_2 Emission from Energy System*. working paper. Institute of Nuclear Technology, Tsinghua University. February.

WU Zongxin et al. 1990. "Energy Demand Forecasting in the Year 2050." working paper. Chinese Society of Energy Research. June.

XI Xiaolin. 1993. *Energy Development and CO_2 Emission in China*. Ph.D. dissertation. Department of Engineering and Public Policy, Carnegie Mellon University. March.

XI Xicun and ZHANG Mingzheng, eds. 1990. *National Planning for Rural Energy Regionalization.*. Beijing: Chinese Statistical Publishing. October.

YANG Fuqiang and Levine, Mark D. 1993. *Overview of China's Energy Forecasting and CO_2 Emissions Models*. LBNL Working Paper. Berkeley: Lawrence Berkeley National Laboratory.

ZHANG Aling. 1993. "China's Energy Demand Forecasting During Economic Transition." working paper. Institute of Nuclear Technology, Tsinghua University. April.

ZHOU Fengqi, ed. 1993. *Environmental Problems in the Energy Development Project in China*. Beijing: China's Building Materials Industry Publishing House. January.

ZHU Liandong and WANG Baohua. 1990. "Energy Demand Forecasting for the Year 2020." working paper. *China's Energy Forecasting in 2050.* September.